NAIC-ID(RS)T-0490-96

NATIONAL AIR INTELLIGENCE CENTER

ARTIFICIAL GUIDE STAR AND RELATED LASER SYSTEM

by

Yan Jixiang and Yu Xin

HUMAN TRANSLATION

NAIC-ID(RS)T-0490-96 15 October 1996

MICROFICHE NR:

ARTIFICIAL GUIDE STAR AND RELATED LASER SYSTEM

By: Yan Jixiang and Yu Xin

English pages: 11

Source: Laser Technology; pp. 37-40

Country of origin: China
Translated by: Leo Kanner Associates
F33657-88-D-2188
Requester: NAIC/TATD/Bruce Armstrong
Approved for public release: distribution unlimited.

THIS TRANSLATION IS A RENDITION OF THE ORIGINAL FOREIGN TEXT WITHOUT ANY ANALYTICAL OR EDITORIAL COMMENT STATEMENTS OR THEORIES ADVOCATED OR IMPLIED ARE THOSE OF THE SOURCE AND DO NOT NECESSARILY REFLECT THE POSITION OR OPINION OF THE NATIONAL AIR INTELLIGENCE CENTER.	PREPARED BY: TRANSLATION SERVICES NATIONAL AIR INTELLIGENCE CENTER WPAFB, OHIO

GRAPHICS DISCLAIMER

All figures, graphics, tables, equations, etc. merged into this translation were extracted from the best quality copy available.

ARTIFICIAL GUIDE STAR AND RELATED LASER SYSTEM*

Yan Jixiang and Yu Xin
Beijing Institute of Technology

Abstract: The requirements of adaptive optics systems on artificial guide stars are discussed and two kinds of laser guide star are introduced briefly. In this paper, the mechanism of sodium guide star and laser systems used in this guide star are emphasized.

KEY WORDS: Adaptive optics, Rayleigh laser guide star, sodium laser guide star.

1. Introduction

The effectiveness of adaptive optics has been repeatedly tested and proven in the laboratory and field. Undoubtedly, satisfactorily compensated images can be achieved with ground-based telescopes as long as the measured target is bright enough to provide hundreds of photo-electrons to each telescope subaperture during an observation period. Typically, this is equivalent to $1\times10^7/m^2 \cdot s$ incident photon flow density, or equivalent to a seventh magnitude star in observations with a visible light. However, if the target itself is weaker than a seventh magnitude star, there should be sufficiently bright reference beacons nearby (within the same isoplanatic region).

---

* This project was funded by the National Natural Sciences

Foundation.

Unfortunately, many stars of practical interest are not bright stars of practical interest are not bright enough, nor there are sufficiently bright natural reference stars nearby. Therefore, one or a number of artificial reference stars should be deployed around the target so as to detect the guide star, and the results of the detection can be used to compensate for the target images.

Laser guide star technology, a technology of using high power lasers to irradiate the sky and taking scattering light as artificial reference beacons, was initially proposed in 1982. Later, a related program was implemented, which was designed to study the theory of adaptive optics using artificial beacons as well as improve the performance of its equipment. Among the investigators, Lincoln Laboratory[1] and Phillips Laboratory [2] were the first to make public the experimental data of laser guide stars used as reference beacons.

In astronomy circles, exclusive research results were first made public first in 1985[3]. In recent years, research papers related to this field have appeared in large numbers[4-7]. In particular, a dozen long articles in volumes 1 and 2 of the Journal of the Optical Society of America (JOSA(A)) published early this year are all focused on this topic.

2. Two Types of Laser Guide Stars

The design of early artificial guide stars was based on Rayleigh back scattering or Raman scattering of nitrogen and oxygen in the air, and the guide stars thus designed were called Rayleigh guide stars. The advantage of these guide stars lies in the fact that the required laser devices are easy to make. However, they also suffer from two obvious disadvantages as follows:

(1) Since most of the air is located at an altitude within 10km above the earth's surface, the point sources of the inverse signals are correspondingly in the same altitude range. In this case, the back scattered waves resulting from Rayleigh scattering will be significantly different from the waves generated from ideal reference sources on top of the atmosphere. According to Fried, this phenomenon is regarded as focal anisoplanatism. If back scattering originates from a higher atmosphere, then its echo waves can be used for detecting high-altitude turbulent flows. Sadly, the atmospheric density rapidly decreases with altitude and the inverse signals from Rayleigh scattering in upper atmosphere are too weak. Under such conditions, for strong enough signals, extremely high power lasers are required, which is very difficult to achieve. (2) With the same flare angle, the coverage area of a low-altitude guide star is much smaller than the one of a high-altitude guide star, in other words, in order to gain an identical correction zone, the number of guide stars in the former case is much larger than in the latter case. For the above-mentioned reason, the Rayleigh guide star has gradually been denied as a key research target.

Another type of guide star technology is based on resonant scattering of the irradiating laser from sodium layers at the altitude of 90-100 kilometers. This kind of guide star is called a sodium laser guide star. Obviously, it can overcome the obstacles that the Rayleigh guide star confronts. Yet, its shortcoming is that it has special requirements for laser performance. However, this problem has gradually been solved with the advances in laser technology. In any case, sodium laser guide star technology now serves as the major direction in developing artificial beacons, which is also the main point in our following discussion.

3. Formation Mechanism of Sodium Guide Stars

The strongest resonant scattering of sodium atoms is line D_2 and line D_1 with 589.2nm and 589.6nm in wavelength, respectively. The corresponding transitions are respectively $3^2S_{1/2} \rightarrow 3^2P_{3/2}$ and $3^2S_{1/2} \rightarrow 3^2P_{1/2}$ (as shown in Fig. 1).

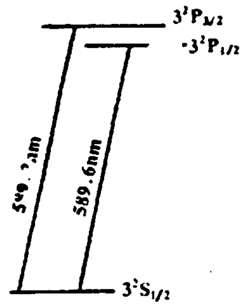

Fig. 1. Transitions of sodium in the upper atmosphere

For a laser beam tuned at the center of line D_2 and propagating vertically upward, approximately ξ=6% photons will be absorbed and therefore, a corresponding number of sodium atoms will be excited from the $3^2S_{1/2}$ state to the $3^2P_{3/2}$ state. When these atoms return to the $3^2S_{1/2}$ state, they emit light with a natural lifetime τ_n, and the typical value of τ_n is more than a dozen ns, while at the altitude of 90km, the time interval τ_c between two consecutive collisions of sodium atoms with air molecules (mainly nitrogen molecules) lasts as long as upwards of 100μs. Thus, the air molecules basically have no effect on τ_n. In other words, it can be believed that the number of photons scattered by sodium atoms is equal to the number of laser photons that they have absorbed. Assume the number of photons emitted by each laser pulse is N, then the number of photons scattered by sodium atoms is $N\xi$. Suppose the scattering is isotropic, then the surface density for receiving scattered photons at the ground is

$$\Delta N_1 = \frac{N\xi}{\pi H^2}$$

where H is the height of the sodium layer; the number of photons received within a circular range with a diameter d is

$$\Delta N = N\xi \frac{d^2}{4H^2} \tag{1}$$

If the received signal-noise ratio is determined by photon count statistics and assume the voltage signal-noise ratio is R, then

$$\sqrt{\eta \Delta N} = R \tag{2}$$

where η is the quantum efficiency of an optical detector.

By substituting Eq. (1) in Eq. (2), the number of photons in each pulse can be given as

$$N = \frac{4H^2R^2}{\xi\eta d^2} \tag{3}$$

or the total energy of each pulse should be

$$E = \frac{4H^2R^2}{\xi\eta d^2} h\nu \tag{4}$$

It is to be noted that in obtaining Eq. (4), the scattered light is assumed to be isotropic. In fact, however, the front and back scattering is stronger than the scattering along other directions. Therefore, to achieve a certain signal-noise ratio, the required number of photons or laser energy would be smaller.

4. Laser System Used in Guide Stars

Here we introduce several laser systems, which are planned to be used, or have already been used, or will possibly be used as adaptive optics telescope artificial guide stars.

1) Keck Telescope System

The Keck telescope, named after William Keck, is a large astronomical telescope, scheduled to be built at the Lawrence Livermore National Laboratory in the United States. This project is expected to have four stages. Completed with an investment of $943 million, Keck I was first employed for scientific observations at the W. Keck Observatory in March, 1993, with satisfactory results. Keck II is to be finished in 1996. Starting from the third stage, the Keck telescope will be equipped with a sodium laser guide star system, for which LLNL worked out three possible options as follows:

(1) CW operating ring dye laser device. This device adopts a 25W argon ion laser pump with a 2W single longitudinal output.

(2) CW operating standing-wave dye laser device. This device adopts a 25W argon ion laser pump, which can simultaneously excite two to three longitudinal modules with a total output power of 5W.

(3) Pulsed operating dye laser device. This system operates in a main oscillation-amplification mode. The output from an in-cavity frequency multiplied Nd:YAG laser pump is matched with the atmospheric sodium layer spectral line D_2 with linewidth 2GHz. Through increasing the number of power amplifiers, the average power may reach dozens and even hundreds of watts. The details of this system will be given in the following description.

2) Pulsed Dye Laser System Used in Artificial Guide Stars

The sodium guide star laser system introduced here was designed and constructed by researchers from the LLNL. The adaptive optics system using this system as a reference source was tested on the telescope at the Lick Observatory. The test results showed that under a medium atmospheric visibility, the Strehl ratio of a 3m diameter telescope system can reach around 0.5 if only the correction system has a sufficient number of driving units and a sufficient bandwidth.

The dye laser device used in this system has two frequency multiplied Nd:YAG laser pumps, its principal block diagram being shown in Fig. 2. The imaginary line block stands for a telescope room. To avoid the effect of large amounts of residual heat on telescope performance, the light source of the pumps and the dye laser main oscillator (DMO) are placed in another room. Only the amplifier of the dye laser is put together with the telescope.

The Nd:YAG laser devices respectively consist of two parts: one part is power supply and Q-modulation control unit, while the

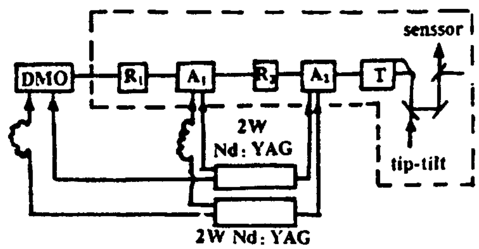

Fig. 2. Block diagram for dye laser system
A_1 - preamplifier A_2 - power amplifier
R - relay optics T - telescope

other part is laser heads. Each laser device consumes around 8kW power, and large amounts of residual heat is carried away by cooling water. Each laser head has three pieces of optical fiber output: one of them connects to the DMO in the same room, while the other two go to the preamplifier and power amplifier, respectively.

The DMO unit includes a dye laser cavity, pattern and frequency selection parts and a phase modulator. Through optical fibers, the DMO output feeds the dye preamplifier. Like the DMO, the dye preamplifier is also a dye box but does not contain any frequency control device. Here, the several milliwatt laser coming from DMO is amplified to hundreds of milliwatts and coupled to the power amplifier so that the power amplifier can output a 25W laser. For a laser output at the hectowatt level, one more amplifier is required for the dye.

The output telescope of the guide star is composed of several negative lens and transmitting lens. To a great degree, the negative lens serve as an aiming mirror for the main telescope.

3) Solid Laser Used in Sodium Guide Stars

In this section, a solid laser system is introduced, which can be used to produce sodium guide stars, according to the reports made by researchers from Lincoln Laboratory, Massachusetts Institute of Technology[8].

The sum frequency of two appropriately modulated Nd:YAG is resonant with the transmitting wavelength of the sodium D_2 line. These two YAG laser devices operate at 1.06μm and 1.32μm, respectively. Compared with the dye laser system, the obtained sodium resonance source has several remarkable priorities: small volume, easy modulation, high reliability and high peak power output, etc. In addition, the sum frequency can be inserted, through modulation, into a seed diode laser for fine modulation.

Fig. 3 shows a principal block diagram of sodium resonance radiation sum frequency. The output of two Nd:YAG laser devices transmits through the common axis of a dichromatic mirror and focuses on a nonlinear crystal $LiNbO_3$, while the sum frequency radiation generated in the crystal directly enters the sodium vapor box. The transmission of the two Nd:YAG laser devices is tuned using an in-cavity tilted standard tool, their tuning curves being shown in Fig. 4. When they are tuned near the center (1.0646μm and 1.3193μm), they can generate sodium resonance radiation (0.5892μm).

The above-mentioned light sources can be used to observe the resonant fluorescence of the earth's sodium layers. The scattered light is collected with telescopes and, by reducing the background light through interference filters and polarizer, is detected with photoelectric multipliers. The photoelectric multiplier reading, recorded with a multichannel counter, is a function to the duration of sodium resonance radiation after being scattered to the atmosphere. Fig. 5 shows signals which return from the earth's upper atmosphere. The early signals are the result of Rayleigh scattering in the atmosphere, while the peak at 600μs corresponds to the sodium resonance radiation, back scattered by the earth's atmosphere.

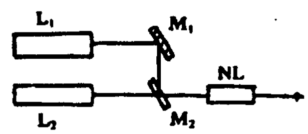

Fig. 3. Schematic of the laser system for sum frequency generation of sodium resonance radiation
L_1 - 1.06μm YAG L_2 - 1.32μm YAG NL - nonlinear crystal

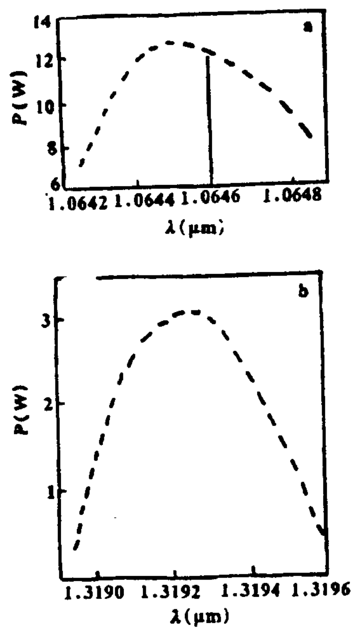

Fig. 4. Tuning curves of the CW 1.06μm and 1.32μm Nd:YAG lasers

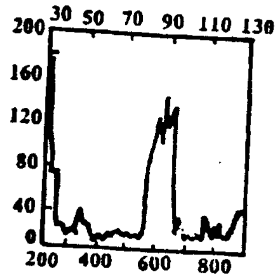

Fig. 5. Sodium resonance radiation back-scattered by earth's atmosphere

REFERENCES

1. Primmerman, C. A., Nature, 1991; 353:141-143.

2. Fugate, R. Q., D. L. Fried, G. A. Ameer, et al, Nature, 1991; 353:144-146.

3. Foy, R. and A. Labeyrie, Astronomy & Astrophys., 1985; 152:129-131.

4. Yan Jixiang, Zhou Renzhong, and Yu Xin, Laser Technology, 1993;17:65-69.

5. Parenti, R. R., and R. J. Sasiela, JOSA, 1994;(11):288-309.

6. Friedman, H., G. Erbert, T. Kuklo et al., SPIE, 1994;2201; 352-363.

7. Happer, W., JOSA, 1994;A(11);263-276.

8. Jeys, T. H., A. A. Brailove, A. Mcordian, Appl. Opt., 1989;28:2588-2591.

On the Authors

Yan Jixiang, male, born December, 1946, is an associate professor, an academic leader of junior and middle-aged staff members in the Beijing University of Technology, a member of the New York Academy of Sciences (NYAS), and a member of the International Engineering Optics Society (SPIE). He is now engaged in research and teaching on adaptive optics, photoelectric statistics, laser theory, technology and applications.

Yu Xin, male, born in 1941, is a professor, an advisor to doctoral candidates, vice president of the Beijing University of Technology, and a member of the Optical Society of America (OSA). He is now involved in research projects including adaptive optics, photoelectric detection of weak signals, etc.

This paper was received for editing on December 20, 1994. The edited paper was received on August 31, 1995.